
China's Ace in the Hole

Rare Earth Elements

By CINDY A. HURST



World's largest rare earth mine,
Bayan Obo, China

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On February 4, 2010, nearly 2 weeks after the Obama administration unveiled a \$6.4 billion arms deal with Taiwan, a Chinese article posted on an online Chinese Communist Party–connected daily newspaper site, as well as on many Chinese blogs and military news sources, suggested banning the sale of rare earth elements (REEs) to U.S. companies as retribution.¹ There was already ample Western concern about potential diminishing access to supplies of REEs, particularly after a 2009 draft report written by China’s Ministry of Industry and Information Technology called for a total ban on foreign shipments of terbium, dysprosium, ytterbium, thulium, and lutetium, and a restriction of neodymium, europium, cerium, and lanthanum exports.² The report immediately caused an uproar among rare earth buyers because China produces approximately 97 percent of the world’s REEs. While there are sources of rare earth around the world, it could take anywhere from 10 to 15 years from the time of discovery to begin a full-scale rare earth operation.

REEs are important to hundreds of high-tech applications, including critical military-based technologies such as precision-guided weapons and night-vision goggles. In exploring the idea of global military might, China appears to be holding an unlikely trump card. The country’s grasp on the rare earth element industry could one day give China a strong technological advantage and increase its military superiority. This article focuses on rare earth elements and their importance to military technology. It also demonstrates how China’s research and development programs, coupled with its vast reserves of REEs, have the potential to make the country a dominant force in the world.

Background

REEs are those chemical elements on the periodic table having atomic numbers 57 through 71 (known as the lanthanides), scandium, and yttrium (atomic numbers 21 and 39). Scandium and yttrium are generally grouped with the lanthanides because of their similar properties and because they are normally found within the same deposits when mined.

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U.S. Geological Survey National Minerals Information Center



Striped high-grade monazite-bastnasite ore

The term *rare earth* is actually a misnomer; these elements are not rare at all, being found in low concentrations throughout the Earth’s crust and in higher concentrations in certain minerals. REEs can be found in almost all massive rock formations. However, their concentrations range from ten to a few hundred parts per million by weight. Therefore, finding them where they can be economically mined and processed presents a challenge.

For at least the past five decades, international scientists and engineers have understood the importance of REEs to military technology. For some, the topic of rare earth has even been shrouded in secrecy. For example, in Russia, REEs were once considered a national secret, with little mention being made about them prior to 1993. Their secret applications were long confined to those organizations, such as the Ministry of Medium Machine Building, Ministry of Nuclear Energy, and Ministry of Nonferrous Metallurgy, that were responsible for the research, design, and production of military equipment and weapons systems. The reason for their secrecy was simple. More than 80 percent of the rare earth industry went into the former Soviet Union’s defense systems.³

Today, many foreign and domestic analysts view REEs as a key factor in developing modern military technology. For example, one Chinese article attributed “night vision instruments with the REE lanthanum” as a “source of the overwhelming dominance of U.S. military tanks during the Gulf War.”⁴ In China, REEs have been

described as a “treasure trove” of new material and the “vitamins of modern industry.”⁵ REEs have also been described as “materials of the future.”⁶

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In 1993, Vyacheslav Trubnikov, first deputy director of Russia’s Foreign Intelligence Service, reportedly sent a letter about REEs to Oleg Soskovets, the Russian Federation’s first vice premier, saying, “We have been receiving information indicating that advanced industrial countries are making increasing use of REEs due to progress in creating and developing qualitatively new, specialized materials with them that increase the critical parameter values of high technology products in the fields of rocket-space and aviation, microelectronics, and electrical engineering.”⁷

Not only are REEs used to greatly improve the qualities and properties in the metallurgy industry, they are also used in the fields of lasers, fluorescents, magnets, fiber optic communications, hydrogen energy storage, and superconducting materials—all key technologies that have been successfully applied to modern militaries.⁸

Military Applications

Of course, not all REEs are created equal. Some experts predict that by 2015 there



Soldier uses magnet locator to search for evidence of extremist activity in Bezel, Iraq

will be a shortage of neodymium, terbium, and dysprosium, while supplies of europium, erbium, and yttrium could become tight.⁹ The neodymium-iron-boron (NdFeB) permanent magnets are so strong that they are ideal for the miniaturization of a variety of technologies, including possible nanotechnologies. Many solid state lasers use neodymium due to its optimal selection of absorption and emitting wavelengths. Consumption of neodymium is expected to increase significantly as more wind turbines come online. Wind may be “free,” but some of the newer generation wind turbines use up to two tons of these magnets. Terbium and dysprosium can be additives to enhance the coercivity in NdFeB magnets.¹⁰ Yttrium is used, along with neodymium, in lasers. Europium is the most reactive of the REEs. Along with its current use in phosphors for fluorescent lamps and television/computer screens, it is being studied for possible use in nuclear reactors.¹¹ Erbium is used as an amplifier for fiber optic data transmission. It has also been finding uses in nuclear applications and metallurgy. For example, adding erbium to vanadium, a metal used in nuclear applications and high-speed tools, lowers the hardness and improves the workability of the metal.

Samarium is another REE used in military applications. Samarium is combined with cobalt to create a permanent magnet with the highest resistance to demagnetization of any material known. Because of its ability to withstand higher temperatures without losing its magnetism, it is essential in both aerospace and military applications. Precision-guided

munitions use samarium-cobalt (SmCo) permanent magnet motors to direct the flight control surfaces (fins). SmCo can also be used as part of stealth technology in helicopters to create white noise to cancel or hide the sound of the rotor blades. These magnets are used in defense radar systems as well as in several types of electronic countermeasure equipment, such as the Tail Warning Function.¹²

According to the U.S. Geological Survey, substitutes are available for many rare earth applications, but they are generally less effective.¹³ Steven Duclos, chief scientist with General Electric Global Research asserts, “There’s no question that rare earths do have some properties that are fairly unique, but for many applications these properties are not so unique that you cannot find similar properties in other materials. [REEs] are just better, from either a weight, strength, or optical property and that’s why people have moved to them.” Duclos went on to explain, “It always comes down to a tradeoff. You can build a motor that does not have rare earth permanent magnets in it. It will be bigger and heavier for a given amount of power or torque that you want.”¹⁴

Some scientists argue that in many cases, while there may

be substitutes, the tradeoff would diminish military superiority. According to George Hadjipanayis, a Richard B. Murray Chair Professor of Physics at the University of Delaware, the alnico and ferrite magnets, the first two permanent magnets ever produced, do not have rare earth in them and their performance is much lower. Hadjipanayis is currently working with a group of researchers to develop a “next generation magnet” that will be stronger than either the NdFeB or SmCo magnets. The project is being conducted using a three-tiered approach:¹⁵

- The University of Nebraska is striving to develop a permanent magnet that does not require rare earth.

- The U.S. Department of Energy’s Ames Laboratory in Iowa is pursuing options that might use new materials based on combinations of rare earths, transition metals, and possibly other elements that have not been used with magnets before.

- The University of Delaware is striving to create a new magnetic material that is based on an idea of “nano-composite” magnets. It is a complex process that could slash the use of neodymium or samarium in magnets by 30 or 40 percent.¹⁶

since the discovery of the NdFeB magnet in 1983, research and development in the United States has been relatively flat



Officer measures Aero Propulsion Laboratory rotor for advanced high-energy alternator designed to produce up to 5 million watts of electricity



Laser guidance during air assault mission in Paktika Province, Afghanistan

Rare earth permanent magnets constitute the widest use of REEs. In the 1960s, the United States was number one in the research and development of magnets. The Nation enjoyed many technological breakthroughs until about the early 1980s. Since the discovery of the NdFeB magnet in 1983, research and development in the United States has been relatively flat.¹⁷

Chinese Influence

The Mountain Pass rare earth mine in California, owned by Molycorp Minerals, was once the largest rare earth supplier in the world. Through the 1990s, however, China's

exports of rare earth elements grew, causing prices worldwide to plunge. This undercut business for Molycorp and other producers around the world, and eventually either drove them out of business or significantly reduced production efforts. According to sources within the industry, rare earth deposits in the United States, Canada, Australia, and South Africa could be mined by 2014.¹⁸ Some experts, such as Professor Jean-Claude Bunzli from the Swiss Federal Institute of Technology, argue that the quantities of rare earth in military technology are low enough that diminishing supplies from China should not be an issue due to Western mining operations

coming on line soon. Still, even if plans to open up new and renewed Western operations do come through, the bigger issue may well be China's growing emphasis in the research and development of REEs, as compared to U.S. efforts, which have decreased dramatically.

The United States paved the way for many of today's modern technologies that China is now capable of exploiting. Part of that effort has entailed scientists focusing on and dissecting the properties and uses of REEs. From about the 1940s to the 1990s, REEs attracted interest in both the U.S. and Chinese academic and scientific communities. Today, however, there are only a small handful of scientists who truly focus on REEs in the United States.

China, on the other hand, has established entire laboratories and teams devoted to the study of REEs. It has various high-profile national programs, such as Program 863 (National High-tech Research and Development) and Program 973 (National Basic Research). While these programs were not put into place to specifically support rare earth-based projects, they are important to China's rare earth industry. These programs offer millions of dollars of government funding for military and civilian research projects that are meant to narrow the technological gap between China and the rest of the world and to give China a foothold in the world arena.

China has a keen forward thinking ability. Its planners pinpoint a potential problem or strength years in advance. Then over time, the country begins to build a strong foundation to achieve its end goal. In 1992, during his visit to Bayan Obo, China's largest rare earth mine, Chinese leader Deng Xiaoping declared, "There is oil in the Middle East; there is rare earth in China."¹⁹ Seven years later, President Jiang Zemin wrote, "Improve the development and application of rare earth, and change the resource advantage into economic superiority."²⁰ Wang Minggin and Dou Xuehong, both from the China Rare Earth Information Center at the Baotou Research Institute of Rare Earth in Inner Mongolia, published a paper in 1996 entitled "The History of China's Rare Earth Industry." They wrote, "China's abrupt rise in its status as a major producer, consumer, and supplier of rare earths and rare earth products is the most important event of the 1980s in terms of development of rare earths."²¹

China knew what it had even before the 1990s. The country established the General

Research Institute for Nonferrous Metals in 1952. In the 1950s, the Bayan Obo mine was built and operated as the iron ore base of the Baotou Iron and Steel Company. In the late 1950s, China began recovering rare earths during the process of producing iron and steel. Since the 1960s, China has emphasized maximizing the use of Bayan Obo, which is located in Inner Mongolia, 80 miles north of Baotou. This effort included employing people to find more effective ways to recover the rare earths. Along with trying to improve separation techniques, China also began other research and development efforts. In 1963, they established the Baotou Research Institute of Rare Earths.

There are two state key laboratories in China: the State Key Laboratory of Rare Earth Materials Chemistry and Applications, which is affiliated with Peking University in Beijing; and the State Key Laboratory of Rare Earth Resource Utilization, in Changchun, in the northern province of Jilin.

Globally, there are two journals dedicated to the research and study of REEs: the *Journal of Rare Earth* and *China Rare Earth Information (CREI) Journal*, both put out by the Chinese Society of Rare Earths. The society was founded in 1980 and comprises tens of thousands of registered scientific and technical researchers of rare earths.²² The number of U.S. scientists devoted to the research and study of REEs today pales in comparison to the vast number in China.

Meanwhile, China had been looking at ways to effectively use REEs in military applications as far back as the early 1960s, when its weapons industry began applied research in the areas of armor and artillery steel. The country produced special rare earth armor steels that became beneficial in manufacturing tanks. In the mid-1960s, China created rare earth carbon steel, the transverse impact value of which was a 70 to 100 percent improvement over the raw carbon steel originally used. Firing tests on the shooting range proved that large-caliber cartridges made with the rare earth armor steels were able to fully meet technical requirements.²³

Since 1963, China has been using rare earth ductile iron in mortar projectiles, which was said to have doubled or tripled the dynamic properties of the projectiles, increasing the number of effective kill fragments several times over and sharpening the fragment edges, which greatly improved the kill power. Prior to using the rare earth ductile

iron in mortar projectiles, China used semi-steel made from high-quality pig iron with 30 to 40 percent scrap steel as the material for pre-chambers of projectile bodies. These older projectile body pre-chambers proved to be much lower in strength, were highly brittle, and produced few effective kill fragments after detonation. In addition, they were not sharp.²⁴

China had been looking at ways to effectively use REEs in military applications as far back as the early 1960s

Rare earth magnesium alloys are fairly strong and lightweight, making them ideal for aircraft. The China Aviation Industry Corporation (AVIC) has reportedly developed 10 brands of rare earth magnesium alloys.



Molycorp

Bastnasite ore mined by Molycorp Minerals in California is source of rare earth elements used in high-tech products



U.S. Army (Matthew Freire)

Bastnasite is a rare earth carbonate mineral

For example, the “ZM₆” cast magnesium alloy, which has neodymium as the main rare earth additive, is being used extensively in such functions as the casings for rear brakes on helicopters, ribs for fighter wings, and rotor lead plates for 30-kilowatt generators. Another high-strength rare earth magnesium alloy, known as “BM25,” which was jointly developed by AVIC and China’s Nonferrous Metal Corporation, has replaced some medium-strength aluminum alloys and is being used for attack aircraft.²⁵

Along with creating more efficient metal alloys, China has carefully studied numerous other uses of REEs, many of which have been used and developed in the United States and by some U.S. allies. These technologies include rare earths as combustibles in bombs; nuclear applications, including military defense, nuclear radiation shielding, and tank thermal radiation shielding technologies; permanent magnets with magnetic properties that are “a hundred times stronger than the magnetic steel used in military equipment in the 1970s”; lasers, including laser rangefinders, laser guidance, and laser communication systems; superconducting materials; sonar; and others.²⁶

In April 2006, Li Zhonghua, a senior engineer, along with Zhang Weiping and Liu Jiaxiang, all from China’s Hunan Rare Earth Materials Research Academy, published a paper entitled “Application and Development Trends of Rare Earth Materials in Modern Military Technology.” After giving a point-by-point narration on the special roles REEs play in modern technology, the authors concluded that there is a close relationship between rare earths and modern military technology. They also noted that the development of the rare earth industry has greatly pushed forward the overall progress of modern military technology, and the heightening of military technology has in turn driven the flourishing growth of the rare earth industry.²⁷

Most press reports today express concern about the future supply and demand of REEs and China’s tightening supplies due to the country’s own growing domestic needs. Yet there is little mention made regarding China’s research and development efforts, which probably deserve the most attention since research and development is the driving force behind China’s increasing success.

More Players

Seeing the potential that REEs hold in modern technologies has likely fueled research and development in other countries, such as North Korea and Iran. For example, in 1988, North Korea formed the Korea International Chemical Joint Venture Company (other names include Chosun [or Choson] International Chemicals Joint Operation Company) to produce REEs from the mineral monazite. According to the U.S. Geological Survey, the plant was reportedly designed to use solvent extraction technology acquired from China’s Yue Long Chemical

Plant near Shanghai.²⁸ Production began in 1991. The monazite is said to come from the Ch'olsan Uranium Mine near Ch'olsan-kun in P'yong'an Province. The Hamhung plant reportedly has the capacity to process 1,500 tons per year of monazite, from which 400 tons of rare earth metals and oxides can be processed.²⁹

In June 2009, North Korean leader Kim Jong-Il visited the Hamhung Semiconductor Materials Factory and the Hamhung Branch of the State Academy of Sciences, where he stressed the need to boost production capacity and the need to accelerate technical updating of the factory to increase the production of rare earth metals. During a campaign to build up the country's research efforts, Kim visited several areas and spoke to the scientists and technicians of the Hamhung Branch. He

North Korean leader Kim Jong-Il stressed the need to increase the production of rare earth metals

was accompanied by members of the Central Committee of the Worker's Party of Korea, including Ju Kyu Chang, a member of the National Defense Commission and First Vice Director of the Ministry of Defense Industry, and the department directors in Organization and Instruction, Financial Planning, and Administration.³⁰

Iran has also embarked on research and development efforts. As early as 1998, its Laser Research Center is believed to have been producing indigenous neodyn [neodymium] yttrium-aluminum (Nd:YAG) lasers, using laser crystals.³¹

In *Nezavisimaya Gazeta*, Alexander Portnov, a professor specializing in geological and mineral sciences, wrote, "There can be no talk of developing nanotechnology if the country does not produce and use rare elements." Portnov argues that a country's extraction, production, and use of rare metals needed for technological innovation are "a precise indicator of its scientific and technical development."³²

It is possible that suitable alternatives to REEs could one day be discovered. In the meantime, however, REEs are critical to many modern technologies. China has recognized the value of REEs for over five decades. While

the United States today leads in technological innovation, China's position in the rare earth industry and its vast reserves and ability to mine and produce them, coupled with its intense research and development efforts, could one day give it a decisive advantage in military-based technologies. The U.S. military must plan for this eventuality and take appropriate actions today if it expects to maintain its lead in military technology. **JFQ**

NOTES

¹ Wang Dake, "Consider Banning the Sale of Rare Earth as Sanctions Against U.S. Companies," *Shanghai Dongfang Zaobao* [Chinese], February 4, 2010, available at <<http://www.dfdaily.com>>.

² Articles discussing the report stated that yttrium was one of the elements expected to be banned. This is likely an error. Ytterbium is much less abundant than yttrium. See Ambrose Evans-Pritchard, "World Faces Hi-Tech Crunch as China Eyes Ban on Rare Metal Exports," *Telegraph*, August 24, 2009.

³ "Russia's Rare Earth, By Way of Prologue: Two Quotes from One Letter," *Interfax AIF*, January 29, 1999.

⁴ "Chinese Government Wins Initial Success in Fight to Protect Tungsten, Antimony, and Rare Earth Elements," Chinese Government Net [Chinese], May 7, 2009.

⁵ Li Zhonghua, Zhang Weiping, and Liu Jiaxiang, "Application and Development Trends of Rare Earth Materials in Modern Military Technology," Hunan Rare-Earth Materials Research Academy [Chinese], April 16, 2006.

⁶ "Russia's Rare Earth, By Way of Prologue."

⁷ Ibid.

⁸ Li, Zhang, and Liu.

⁹ Robin Bromby, "Caution, Rare Earths Ahead," *The Australian*, April 26, 2010, available at <<http://www.theaustralian.com.au/business/mining-energy/caution-rare-earths-ahead/story-e6frg9ex-1225858477751>>.

¹⁰ Magnets will lose their magnetism at certain elevated temperatures. Neodymium can only be used at near room temperatures. Adding the terbium or dysprosium gives it a higher *coercivity*, which allows the magnet to withstand higher temperatures before losing magnetism.

¹¹ Europium sesquioxide (Eu₂O₃) has been tested as neutron absorbers for control rods in (fast breeder) nuclear reactors. Jean-Claude Bunzli, email correspondence with author, April 29, 2010.

¹² James B. Hedrick, "Rare Earths in Selected U.S. Defense Applications," paper presented at the 40th Forum on the Geology of Industrial Minerals, Bloomington, IN, May 2-7, 2004.

¹³ "Rare Earth," U.S. Geological Survey, *Mineral Commodity Summaries*, January 2009, 131.

¹⁴ Steven Duclos, telephone interview with author, March 2, 2010.

¹⁵ Jeremy Hsu, "Scientists Race to Engineer a New Magnet for Electronics," *Live Science*, April 10, 2010.

¹⁶ Ibid.

¹⁷ For more information on the history of China's rare earth industry, read Cindy A. Hurst, *China's Rare Earth Elements Industry: What Can the West Learn?* (Washington, DC: Institute for the Analysis of Global Security, March 2010), available at <www.iags.org/rareearth0310hurst.pdf>.

¹⁸ "Rare Earth Materials in the Defense Supply Chain," Government Accountability Office in response to the National Defense Authorization Act for Fiscal Year 2010 (Pub. L. No. 111-84), April 14, 2010.

¹⁹ "Rare Earth: An Introduction," Baotou National Rare-Earth Hi-Tech Industrial Development Zone, accessed April 28, 2010.

²⁰ Ibid.

²¹ Wang Minggin and Dou Xuehong, "The History of China's Rare Earth Industry," in *Episodes from the History of the Rare Earth Elements*, ed. C.H. Evans (Dordrecht, Netherlands: Kluwer Academic Publishers, 1996), 131-147.

²² According to the China's Society of Rare Earths Web site, there are more than 100,000 "registered experts." However, approximately one-quarter to one-third of these "experts" are likely administrative personnel.

²³ Li, Zhang, and Liu.

²⁴ Ibid.

²⁵ Ibid.

²⁶ Ibid.

²⁷ Ibid.

²⁸ Solvent extraction technology was originally developed in the United States, then bettered by the French company Rhône Poulenc, which became Rhodia. In the 1980s and 1990s, this was the best separation technology available. Eventually, after much hesitation, Rhodia transferred the technology to Baotou under the form of a joint venture in Baotou, China.

²⁹ James B. Hedrick, "Rare Earths," *U.S. Geological Survey Minerals Yearbook*, 2002, 61.7.

³⁰ "Kim Jong Il Provides Field Guidance to Factory and Scientific Institution," KCNA, June 30, 2009, available at <<http://www.kcna.co.jp/item/2009/200906/news30/20090630-26ee.html>>.

³¹ The original source of this information breaks out Nd:YAG as neodymium:ytterbium-aluminum garnet lasers. This is likely inaccurately depicted since the Nd:YAG is produced with yttrium, and not ytterbium. See Charles D. Ferguson and Jack Boureston, "IAEA Pubs Iranian Laser-Enrichment Technology in the Spotlight," *Jane's Regional Security Issues*, June 18, 2004.

³² Alexander Portnov, "The Metallic Aftertaste of Scientific Progress," *Nezavisimaya Gazeta*, September 10, 2008.